Nanosecond Imaging of Shock- and Jet-Like Features

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***Abstract*—The production of shock- and collimated jet-like features is recorded from the self-emission of a plasma using a 16- frame camera, which can show the progression of the interaction over short (100s ns) durations. A cluster of laser beams, with intensity 10^{15} W/cm^2, was focused onto a planar aluminum foil to produce a plasma that expanded into 0.7 mbar of argon gas. The acquisition of 16 ultrafast images on a single shot allows prompt spatial and temporal characterization of the plasma and enables the velocity of the jet- and shock-like features to be calculated.**

***Index Terms*—Laser beams, plasma diagnostics, plasmas, shock waves.**

HIGH-SPEED plasma flows can be created in the laboratory using lasers, and are used to gain a better understanding of astrophysical objects and processes. Hydrodynamic scaling [1] allows the physics occurring within large-scale objects to be reproduced on much smaller scales within a laboratory environment. Several areas of particular interest to laboratory astrophysics are the magnetization of interstellar plasmas [2], plasma jets, and shock waves, which are common features of active galactic nuclei and young stellar objects.

Supersonic, collimated jets have been previously observed from interactions with planar targets. This experiment uses a planar aluminum foil to simultaneously produce shock- and jet-like features from an intense laser–plasma interaction. The temporal development of these jets and shocks are on the nanosecond scale and require a fast-framing camera, such as the one used in this experiment, to capture the evolution of the plasma and its interaction with a background gas and obstacle.

This experiment was carried out using the Vulcan laser system at the Rutherford Appleton Laboratory. The six infrared beams of 2 ns duration, with a total energy of 1.2 kJ, were clustered to a single, 300 μm focal spot on a 5 mm $\times$ 5 mm, 10 μm thick Al planar foil target. The target was enclosed in a chamber containing 0.7 mbar of argon gas. The evolution of the plasma from the target and its propagation through the argon was then imaged using a 16-frame camera. Shock- and jet-like features are seen, as shown in Fig. 1.

A fast multiframing camera provides insight into the dynamics of plasmas driven by high-energy laser systems, such as Vulcan. The images were taken using a Specialized Imaging SIM16 camera that uses framing speeds of up to 200 000000 frames/s. The camera contains 16 CCD chips coupled to microchannel plates fitted with an S25 photocathode and a minimum gate width of 5 ns. The images included in Fig. 1 are taken with a 5 ns exposure and evenly spaced at 35-ns intervals, where time $t = 0$ ns corresponds to when the laser beams hit the target. The image is formed from the self-emission of the plasma, filtered using a 620-nm interference filter, with a 10-nm full-width-half-maximum bandwidth, to observe emission from Ar I and Ar II lines. The most intense lines are at 617 and 624 nm.

In the images at early time, <90 ns, the target is glowing and a hemispherical shock is launched, following plasma breakout at the target rear surface. This is followed by a faster moving jet-like plasma. The jet is driven by momentum conservation as target material ablates away from the target front surface. The jet propagates into the Ar gas, centered along the target surface normal, and moves toward an induction (B-dot) probe [2] used to measure changes in the magnetic field. This probe is placed at 2-cm distance from the Al foil target. The jet-like plasma acts as a piston driving a bow shock-like feature in the Ar ahead of the jet, which separates from the jet by 125 ns. The distance moved by each feature in the images can be used to calculate their velocities. Monitoring the hemispherical shock-like front, calculations suggest that it initially expands at $\sim$160 km/s perpendicular to the target surface, and as the shock expands and decelerates, it slows to $\sim$45 km/s by 545 ns. The bow shock-like feature moves along the surface normal with an initial velocity of $\sim$150 km/s slowing down to $\sim$80 km/s by 475 ns. These velocities are estimated to have a $\sim$10% error associated with them.

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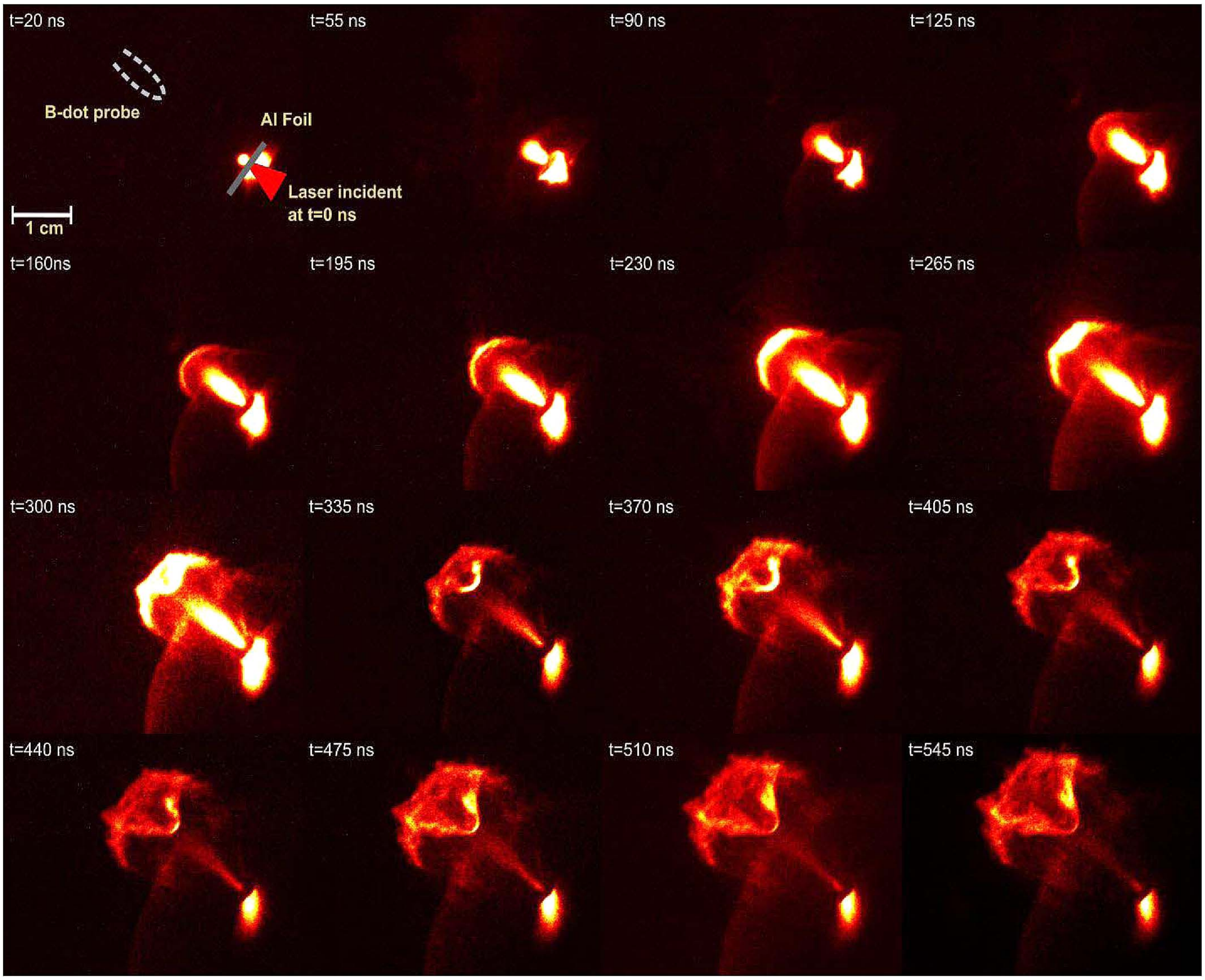

Fig. 1. Images taken using a fast-framing camera with a 5 ns exposure, of the self-emission occurring from a plasma created in a laser interaction with an Al foil. Shock- and jet-like features are observed evolving over time as the plasma expands out and around a B-dot probe. The times shown in each image are relative to when the laser cluster irradiates the Al foil.

At ~265 ns, the jet column reaches and collides with the B-dot probe, which disrupts the flow and changes the magnetic fields. The flow stagnates, resulting in increased emission as the plasma density and temperature rise. The boundaries of the probe are clearly seen, and the stagnating plasma appears to drive other structures to manifest within the bulk emissive region, illustrating the complex flows that result. Time-resolved images of this type allow study of the dynamic evolution of the fluid, from which growth rates and hydrodynamic instabilities can be directly inferred.

In conclusion, the framing camera is an effective tool for observing an interaction, where shock- and jet-like features are created and developed over nanosecond time scales. A fast-framing camera, coupled with scaled hydrodynamic simulations, could assist in understanding how a jet or shock wave might develop and progress in astrophysical objects [2]. There are also benefits for using such a camera on large-scale experiments, such as those conducted at NIF, where monitoring laser–plasma interactions over larger time durations will be invaluable when shot availability is limited.

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